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TOP PRODUCTION CROSS SECTION FROM CDF

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Recent top physics results from the CDF at a center-of-mass energy of 1.96 TeV are presented. Measurements of the $t\bar{t}$ production cross section in all three decay channels, using a set of complementary experimental methods, are presented as well as results of a search for single top production.

1 Introduction

Since the discovery of the top quark in 1995 by the CDF and DØ collaborations¹, an extensive program to fully determine the properties of this fundamental particle of the Standard Model is underway. These properties are important not just to characterize the top quark, but also for the understanding of its relationship to other particles in the model. Many theoretical models, that attempt to circumvent the theoretical shortcomings of the Standard Model, identify the top quark as a possible window into electroweak symmetry breaking and predict the existence of new particles that would affect top physics.

Run II at the Fermilab Tevatron, with proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV, offers a unique opportunity to do precision top physics. With the increase in center of mass energy with respect to Run I, the $t\bar{t}$ pair production cross section is expected to increase by 30 to 40%. The study of the top quark at CDF², also provides a testbench for tools and techniques which will be useful for physics analysis at the LHC.

2 Top Quark Properties in the Standard Model

Top quarks are pair-produced at the Tevatron via quark-antiquark annihilation (85%) or via gluon fusion (15%), with a NLO cross section³ of $6.7^{+0.7}_{-0.9}$ pb³ for $M_{\text{top}} =$

175 GeV/c²; single top production is suppressed by a factor of two relative to $t\bar{t}$ production. The large mass of the top quark has a significant impact on its phenomenology. Unitarity constraints in the CKM matrix require large values for V_{tb} , thus the top quark decays before hadronization to a W boson and a b quark.

The experimental signature of a $t\bar{t}$ event is 2 b jets along with the decay products from the two W bosons. Each W decays either to a charged lepton and a neutrino that remains undetected, or to a quark-antiquark pair that appears in the detector as jets. The decay mode of the W's are used to categorize $t\bar{t}$ events into *dilepton* ($l^+\nu b l^-\bar{\nu}\bar{b}$, ~11% of all $t\bar{t}$ events), *lepton+jets* ($l\nu b q\bar{q}\bar{b}$, ~44%) and *all hadronic* ($q\bar{q}bq\bar{q}\bar{b}$, ~44%) channels.

3 Top Quark Pair Production Cross Section

At CDF, we measure the $t\bar{t}$ production cross section in all three categories using either counting experiments or by fitting the data to kinematics distributions that can discriminate background from signal.

3.1 Dilepton Channel

The dilepton channel is characterized by two leptons with high transverse momentum (P_T) and missing energy (\cancel{E}_T)⁴ from the undetected neutrinos and two jets from the b quarks. This final state has the highest signal

to noise ratio but suffers from limited statistics. We currently use three different methods to measure the cross section in the *dilepton* channel.

The first analysis is a counting experiment similar to what was used in Run I, in which two well identified isolated, high- P_T electrons or muons are selected. The second analysis does not require lepton identification on the second lepton but only asks for an isolated high- P_T track. This increases the overall acceptance as well as acceptance from τ via their one-prong hadronic decay. Both methods measure the cross section using $\sim 200 \text{ pb}^{-1}$ of data by counting the background subtracted signal and correcting for detector acceptance and reconstruction efficiencies⁵. Both measurements are consistent with one another and with the Standard Model predictions and the combined cross section obtained is:

$$\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(\text{stat.})^{+1.7}_{-1.2}(\text{sys.}) \text{ pb} \quad (1)$$

In the third method⁶, we take advantage of the different kinematic behavior of $t\bar{t}$ events with respect to other Standard Model processes in the two-dimensional E_T and jet multiplicity space. A simultaneous fit of the data to the expected kinematic shapes from signal and background templates is performed using 193 pb^{-1} of data. The fit treats $t\bar{t}$, WW and $Z \rightarrow \tau\tau$ as three distinct signal processes and WZ, ZZ, $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ as one combined background shape. From the result of this fit, we extract a $t\bar{t}$ production cross section of $8.6^{+2.5}_{-2.1}(\text{stat.})^{+1.1}_{-1.1}(\text{sys.}) \text{ pb}$ and a WW production cross section of $12.6^{+3.2}_{-3.0}(\text{stat.})^{+1.2}_{-1.2}(\text{sys.}) \text{ pb}$.

3.2 *Lepton+Jets Channel*

Analyses in the *lepton+jets* channel select events in which one W decays leptonically to electron or muon. The sample size is larger than the dilepton sample, but there is a significant background contamination from

QCD $W + jets$. The purity of the sample can be improved by the identification of at least one b-jet. We currently have developed two different b-tagging algorithms. The first one makes use of the long lifetime of the b quarks to reconstruct a displaced secondary vertex (*SVXtagger*). The second one (*SLTtagger*) identifies the soft muon from semileptonic b-decay. The signal to noise ratio can be further improved by requiring the scalar sum of the energy in the event, H_T , to be greater than 200 GeV.

Counting experiments

By selecting *lepton+jets* events with three or more jets, $H_T > 200 \text{ GeV}$ and at least of the jets tagged as a b-jet by the *SVXtagger*⁷, the measured cross section from 162 pb^{-1} of data is:

$$\sigma_{t\bar{t}} = 5.6^{+1.2}_{-1.0}(\text{stat.})^{+1.0}_{-0.7}(\text{sys.}) \text{ pb} \quad (2)$$

If we use the *SLTtagger*⁸ instead of the *SVXtagger*, the result obtained using 193 pb^{-1} of data yields to a $t\bar{t}$ production cross section measurement of:

$$\sigma_{t\bar{t}} = 4.2^{+2.9}_{-1.9}(\text{stat.})^{+1.4}_{-1.4}(\text{sys.}) \text{ pb} \quad (3)$$

We also measure the $t\bar{t}$ cross section using events where two jets have been tagged with the *SVXtagger*. Since this sample provides "golden" events for the measurement of the top mass, due to the reduced combinatorics from the jet-parton match, we have developed a "looser" *SVXtagger*² which has a higher b-tagging efficiency at the expense of a higher rate of mistags from light quark jets. The measured cross section using the "standard" and "looser" *SVXtagger* are given in equations 4 and 5 respectively.

$$\sigma_{t\bar{t}} = 5.4^{+2.4}_{-1.9}(\text{stat.})^{+1.1}_{-0.9}(\text{sys.}) \text{ pb} \quad (4)$$

$$\sigma_{t\bar{t}} = 8.2^{+2.4}_{-2.1}(\text{stat.})^{+1.8}_{-1.0}(\text{sys.}) \text{ pb} \quad (5)$$

Kinematic fits

Instead of counting signal and background events, one can extract the fraction of $t\bar{t}$

events in the lepton+jets sample by fitting one or more kinematic variables in the data to the expected shapes from signal and backgrounds. We present three different methods^{10–11} using this technique.

The first method uses the discriminating power of H_T while the second method uses a neural network trained on seven kinematic variables to extract the $t\bar{t}$ fraction in the data. Note that neither of the methods require b-tagging. The $t\bar{t}$ cross section using 193 pb^{-1} of data are measured to be $4.7^{+1.6}_{-1.6}(\text{stat.})^{+1.8}_{-1.8}(\text{sys.})$ pb and $6.7^{+1.1}_{-1.1}(\text{stat.})^{+1.6}_{-1.6}(\text{sys.})$ pb respectively.

The third method requires at least one jet tagged with *SVXtagger*. The kinematic variable used for the template is the E_T of the highest E_T jet in the event. This method, using 162 pb^{-1} of data, yields to a cross section of:

$$\sigma_{t\bar{t}} = 6.0^{+1.5}_{-1.8}(\text{stat.})^{+0.8}_{-0.8}(\text{sys.}) \text{ pb} \quad (6)$$

3.3 All Hadronic Channel

The *all hadronic* channel provides a very large event sample but is very challenging due to the overwhelming multi-jet QCD background. The poor signal to noise ratio of 1:2500 is improved to 1:4 by topological cuts, a cut on the total energy in the event and at least one jets tagged with *SVXtagger*. The cross section is measured by counting signal and expected background in events with six to eight jets¹². The extracted cross section from 165 pb^{-1} of data is:

$$\sigma_{t\bar{t}} = 7.8^{+2.5}_{-2.5}(\text{stat.})^{+4.7}_{-2.3}(\text{sys.}) \text{ pb} \quad (7)$$

3.4 Cross Section Summary

Results from the various top quark pair production cross section are summarized in figure 1. All results are found to be consistent with each other and with the Standard Model prediction³.

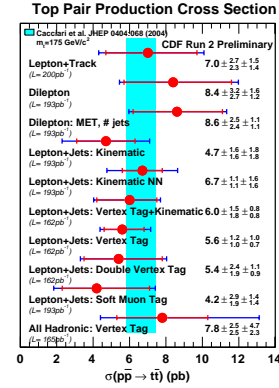


Figure 1. Summary of the measured $t\bar{t}$ cross section from CDF. The band indicated the theory expectation.

4 Single Top

Within the Standard Model, top quarks are also expected to be produced singly by the electroweak interaction involving a Wtb vertex. At the Tevatron, the two relevant modes are the t-channel through Wg fusion and the s-channel via a virtual W . The measurement of the single top production is particularly interesting since it would provide a direct determination of $|V_{tb}|$ but also offer sensitivity to new physics, particularly in the s-channel, to the production of new charged gauge bosons, and in the t-channel to anomalous couplings and flavor changing neutral currents. The extraction of a single top signal is challenging due to the W +jets background.

The event selection consists of isolating events with a W and two jets, one of which is tagged as a b-jet with the *SVXtagger*. We perform two separate searches in 162 pb^{-1} of data¹³, one for the combined s- and t-channel to optimize sensitivity to a single top signal, and a separate search to measure the rate of the two single top processes individually thus increasing sensitivity to new physics. For the combined search a likelihood fit to the H_T distribution is used. For the separate search, the distribution of $Q_l \times \eta_q$, where Q_l is the

charge of the lepton from the W decay and η_q is the pseudorapidity of the untagged jet, is used since it exhibits a distinct asymmetry for the t-channel. We find no evidence of electroweak single top quark production and set upper limits of 10.1 pb at 95% C.L. for the t-channel cross section, 13.6 pb for the s-channel and 17.8 pb for the combined search.

5 Summary and Conclusions

In this article preliminary measurements of the top pair production cross section and limits on the single top production cross sections were presented using a data set twice as large as the Run I data set. All the measurements are found to be in agreement with the Standard Model expectation but are still statistically limited. As the amount of Run II data collected increases and the systematic uncertainties determined from data decrease, CDF will be able to achieve even more precise measurements of the top quark properties and probe for physics beyond the Standard Model.

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